Constellation-X
IGM and Galactic Halo Science

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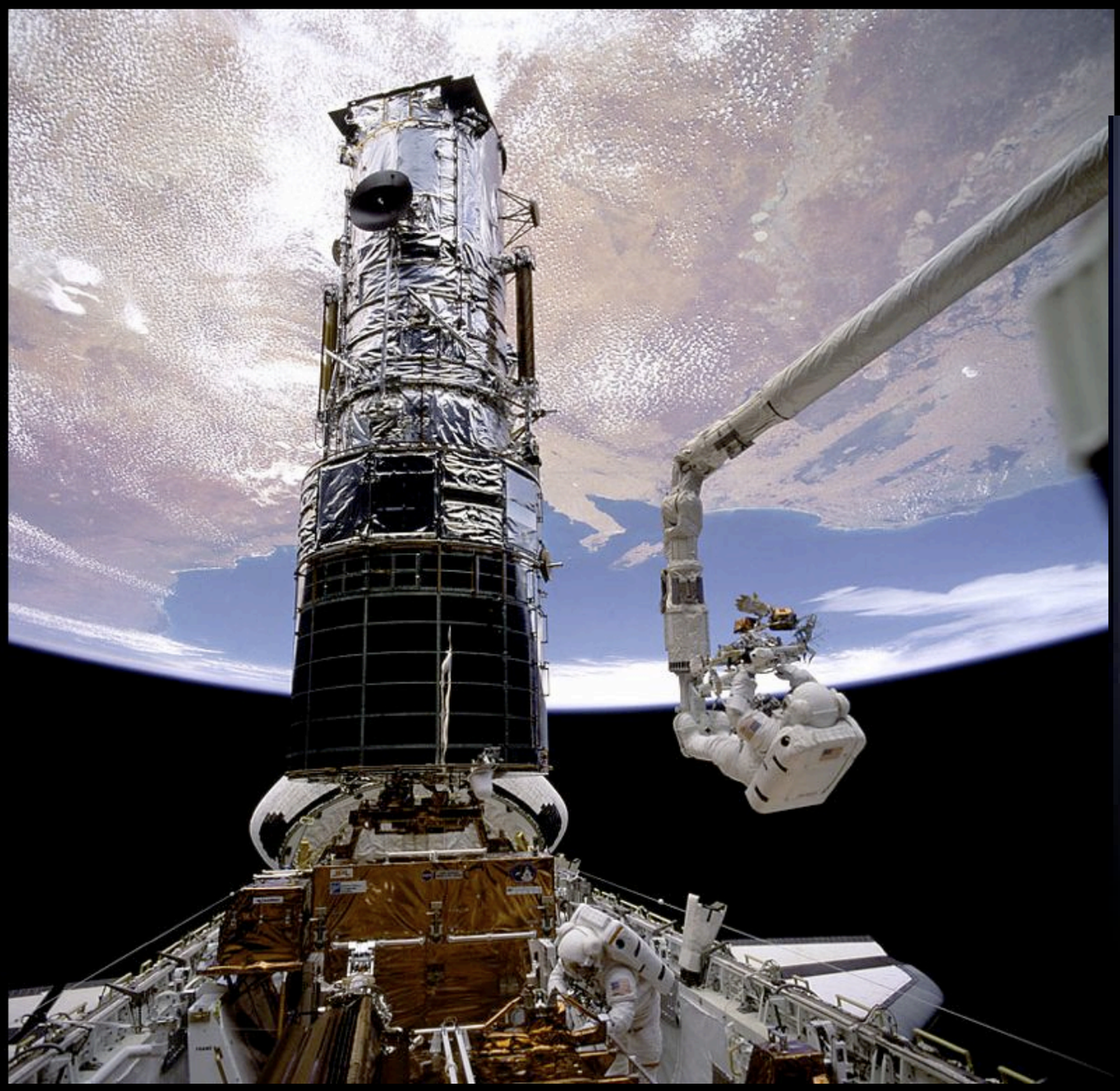
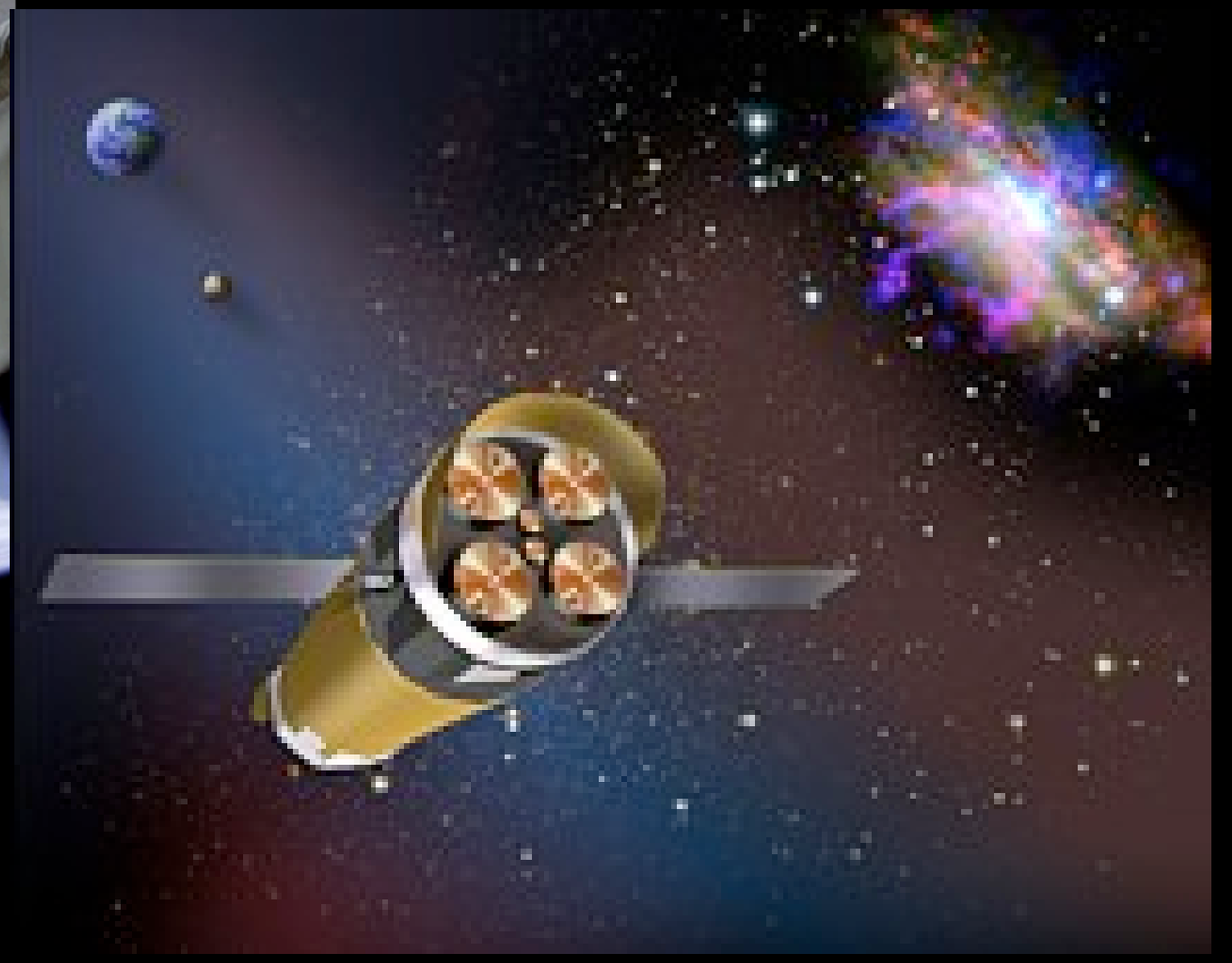
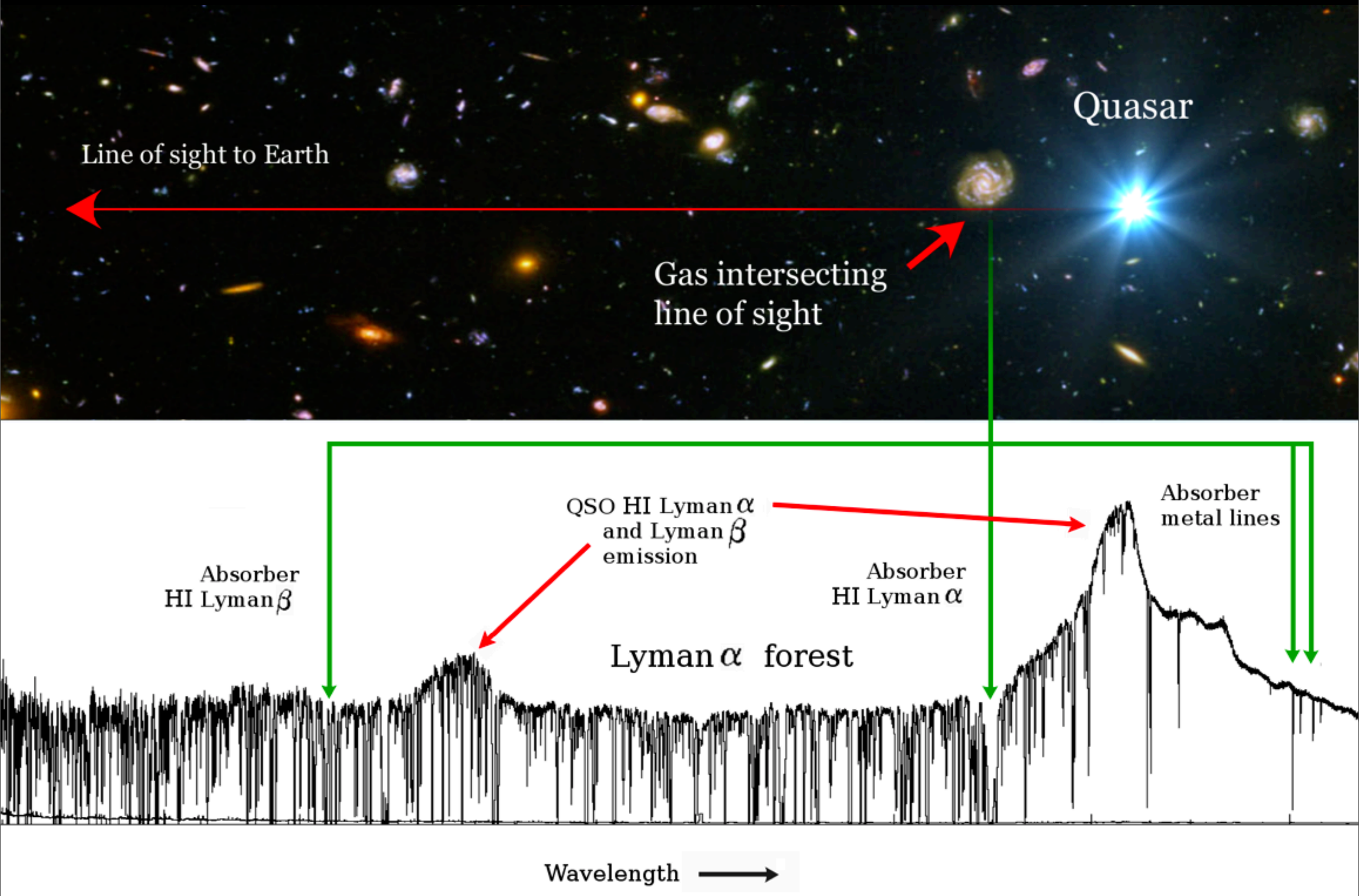




Large galaxy

Metal-polluted regions

IGM at z = 0.1


Quasar
Line of sight to Earth
Gas intersecting
line of sight
QSO HI Lyman α
and Lyman β
emission
Absorber
HI Lyman β
Absorber
HI Lyman α
Absorber
metal lines
Lyman α forest
Wavelength

IGM, WHIM, Missing Baryons

Joint UV/X-ray Program

- We have accounted for ~50% of low-z baryons

Are the rest (50%) in hotter gas (1-3 x10^6 K) ?

Crucial test of baryon shocks in LSS

*10% in galaxies/groups, ~30% in Lyα forest,
~10% in OVI-bearing WHIM ($10^{5\text{-}6}$ K)

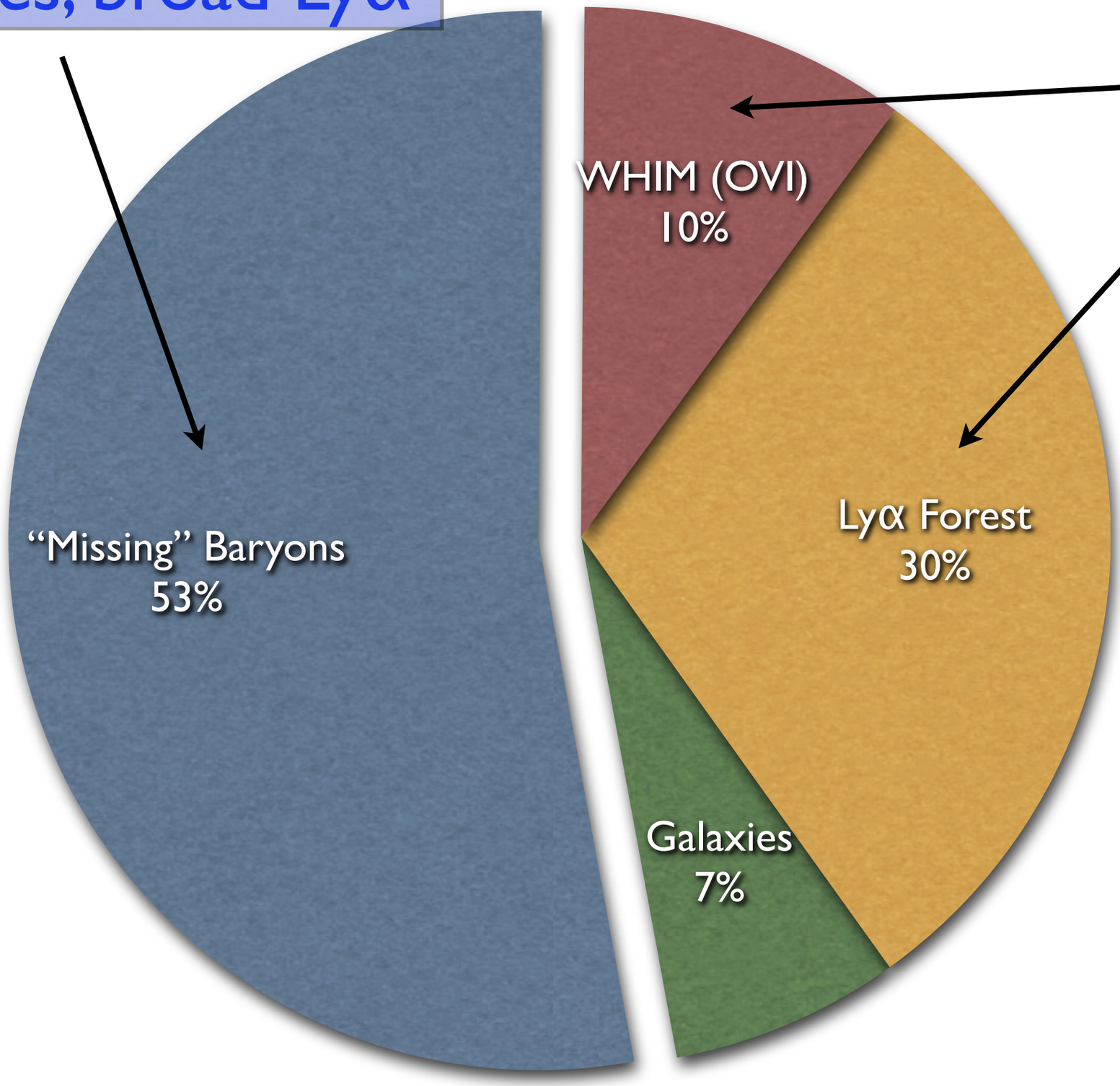
* HST/FUSE found ~100 WHIM/OVI absorbers

- There are significant systematic uncertainties

X-ray absorbers (Con-X) are needed to complete the baryon surveys and to understand feedback to IGM in winds

Baryon Census (low-z)

Probed by X-ray lines, broad Lyα



Both of these are uncertain

IGM Systematics:

- EUV radiation field
- Oxygen metallicity
- Ioniz corrections
- Cloud geometry

Major Cosmological Issues

(1) Are models of large-scale structure correct?

(baryons in Cosmic Web, shocked filaments)

(2) What are thermodynamics of Cosmic Web?

(3) How strong is feedback from galaxy winds?

(4) What is the extent of gaseous halos?

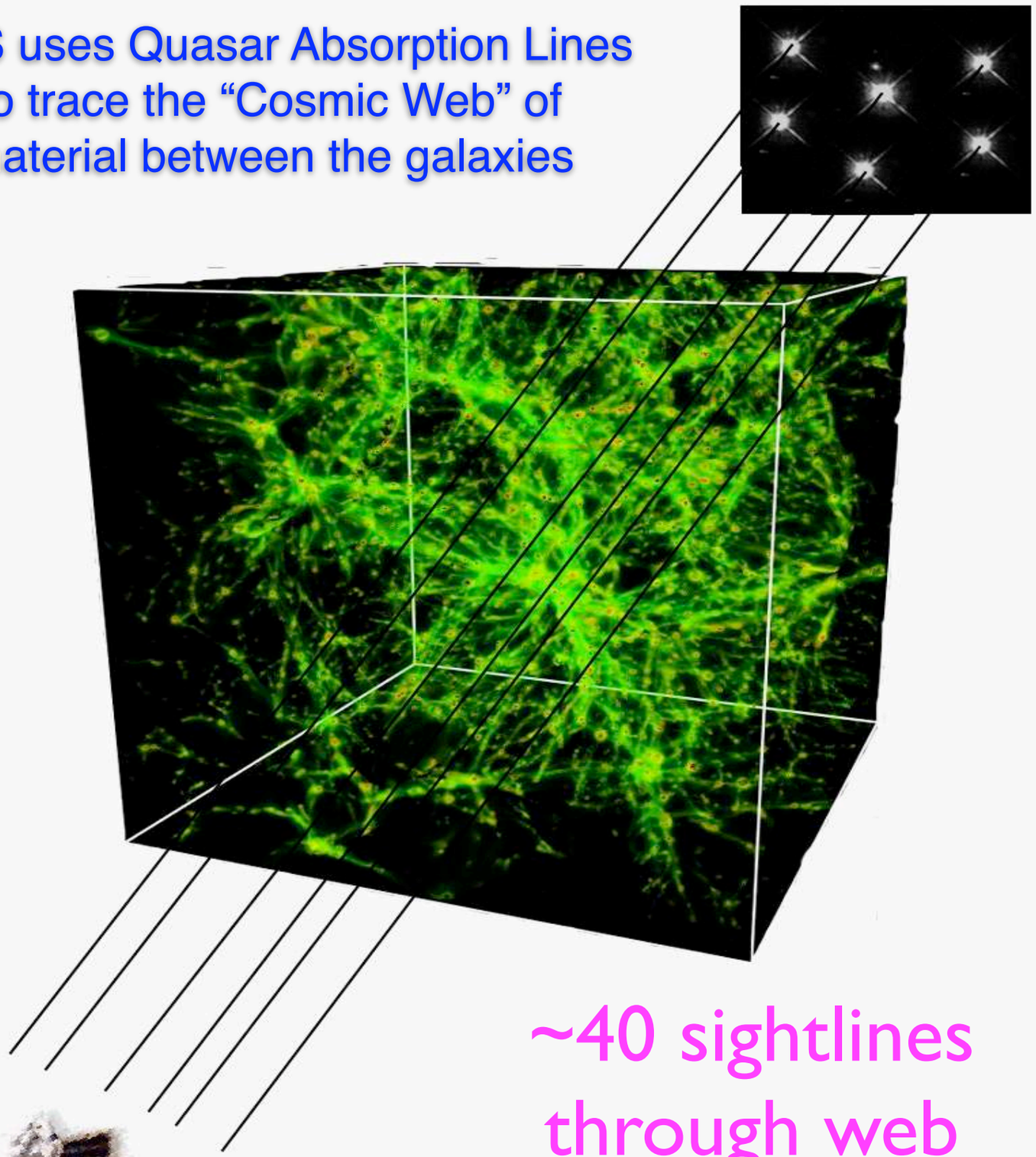
(5) How does gas accrete from IGM into halos?

Hubble-COS

~250 GTO orbits for IGM science (over 3 yrs)

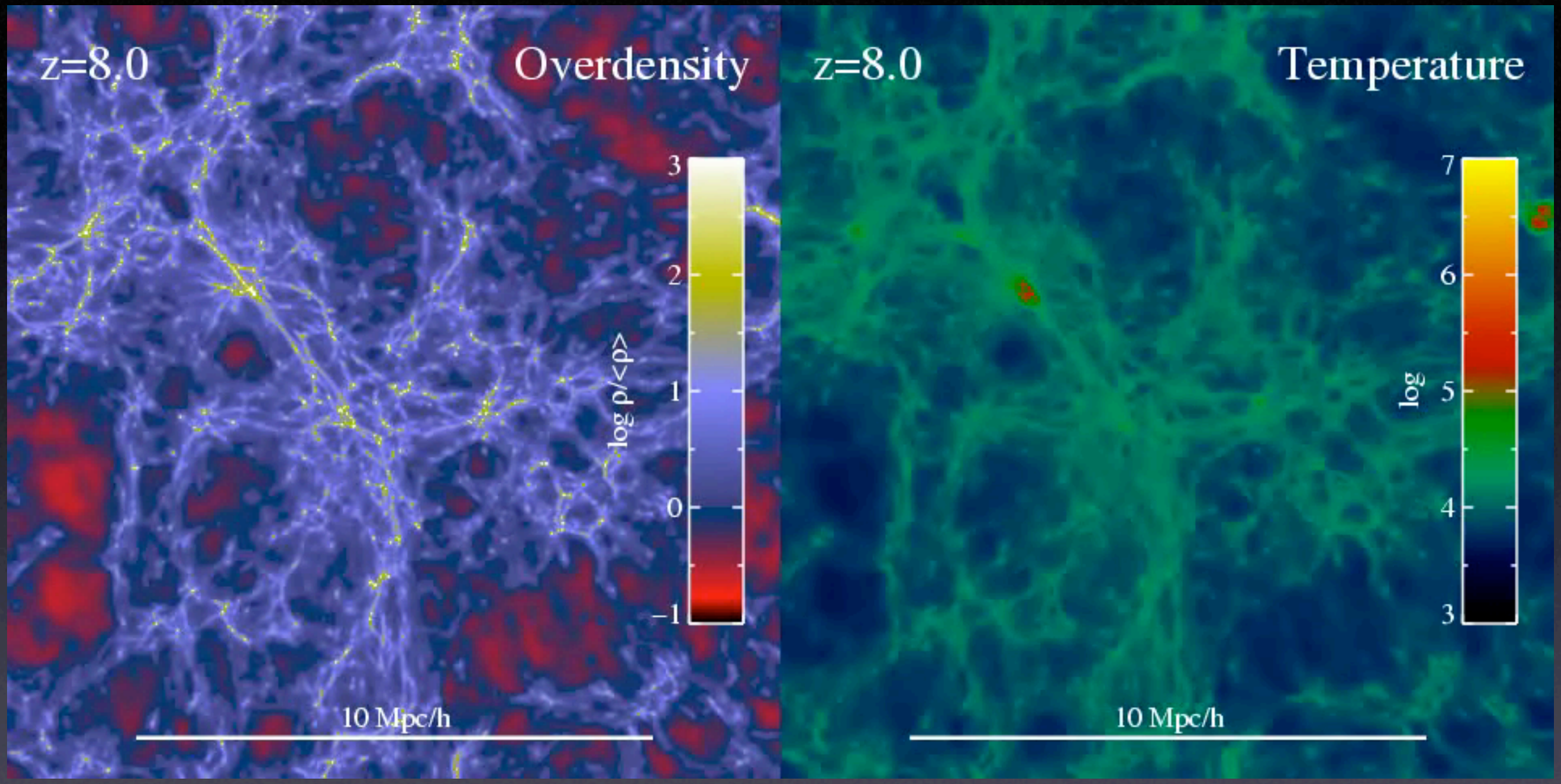
Much more time available + new HST Treasury Projects (cycles 18-20)

COS uses Quasar Absorption Lines to trace the "Cosmic Web" of material between the galaxies



~40 sightlines through web filaments, galactic halos, WHIM

Simulations of Structure Formation



Oppenheimer, Davé, & Finlator (Princeton Univ.)

IGM Evolution from z = 8 → 1.5

COS-GTO Studies of IGM

253 Hubble Orbits

$\Delta z \approx 10$ pathlength

Large-Scale Structure in Baryons .....

Cloud sizes, Lyα, metal lines, blazars (broad Lyα absorbers), starburst wind outflows, galaxy halos, high-velocity clouds

100 orbits
18 QSOs

WHIM in Cosmic Web and Halos .....

High ions (O IV/V/VI, N V, C IV), BLAs, survey redshifts z out to 0.67

100 orbits
17 QSOs

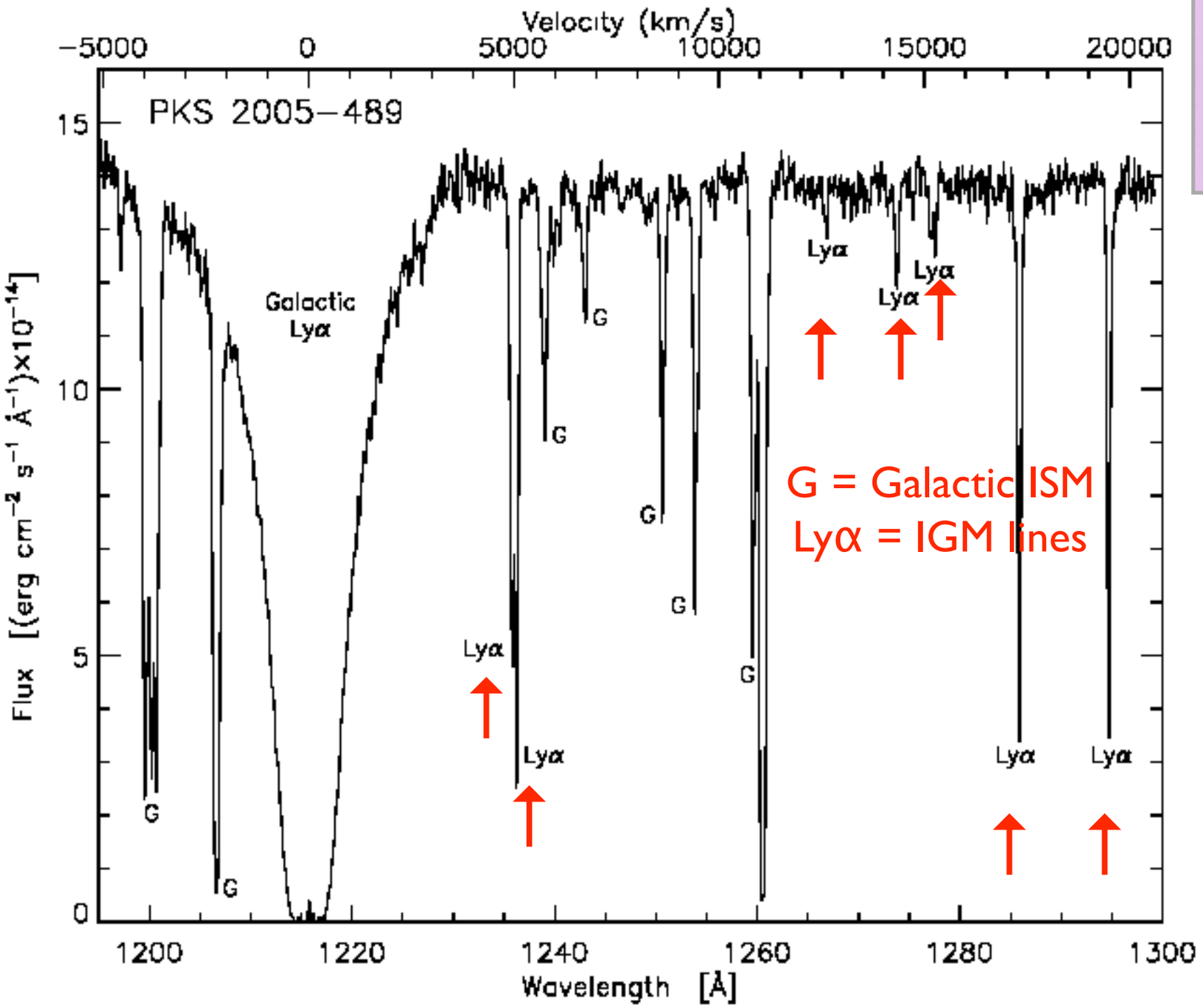
Great Wall Tomography .....

29 orbits, 4 QSOs

He II Reionization Epoch .....

27 orbits, 4 AGN

Hubble/STIS Spectrum of low-z Lyα absorbers toward the blazar PKS 2005-489



Lyα absorbers

$N_{HI} = 10^{13\text{-}15}$ cm^{-2}

$M_H \approx 10^{8\text{-}9}\ M_{sun}$

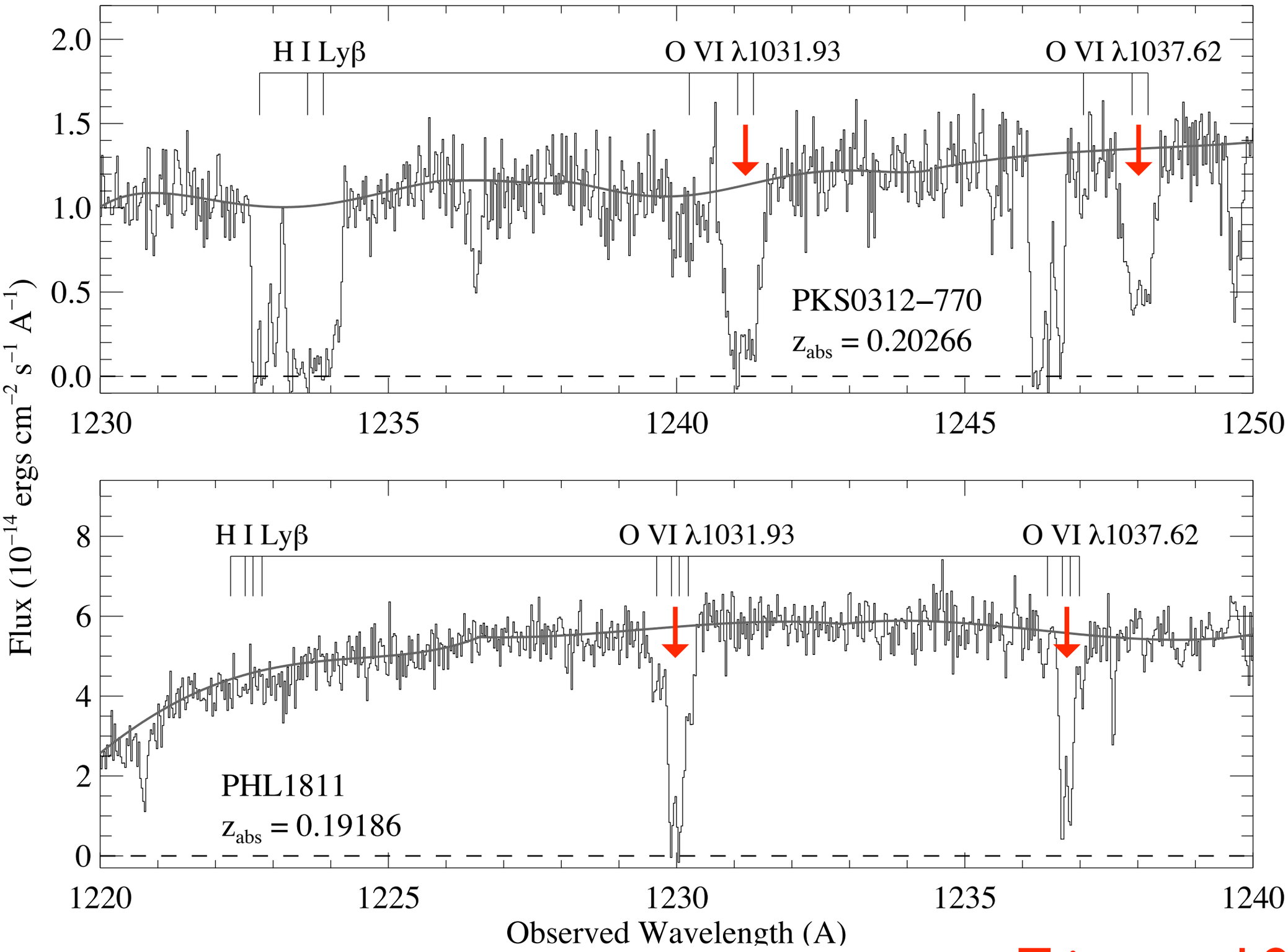
(with ionization correction $f_{HI} \approx 10^{-4}$ to 10^{-5} for HI)

One Lyα line every 2300 km/s (dN/dz ≈ 130)

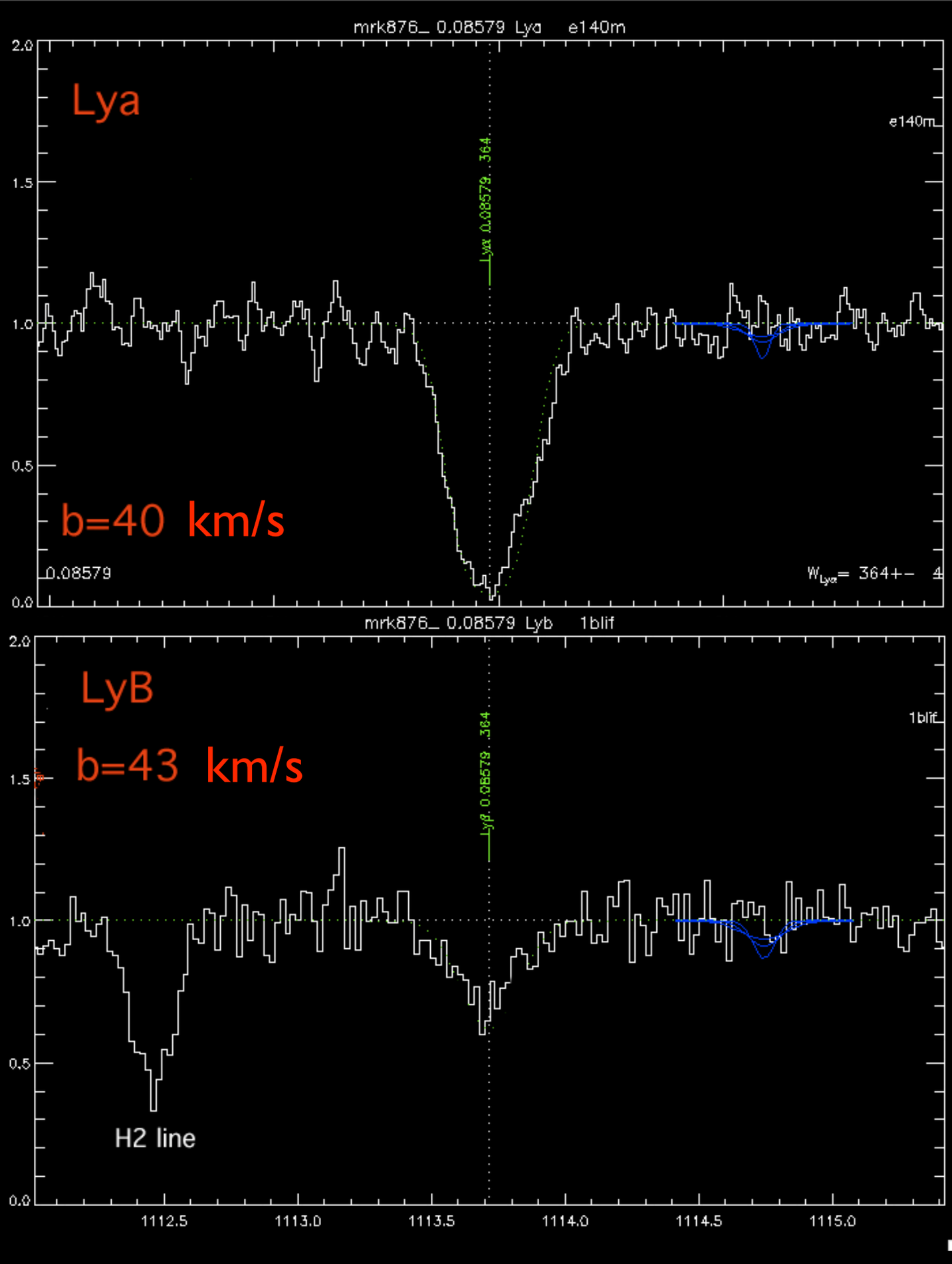
(EW > 30 mA)

Many more at 10 mA

O VI absorbers (low-z IGM)



Tripp et al 2008



Broad Lyα Absorber

BLA system (z=0.0878) toward Mrk 876

Good agreement between Lyman-series and curve of growth

$b_{Lya,b} \sim b_{COG} = 44$ km/s

MRK478

13.00 h

18.93 h

7.07 h

10000

7500

5000

2500 km/s

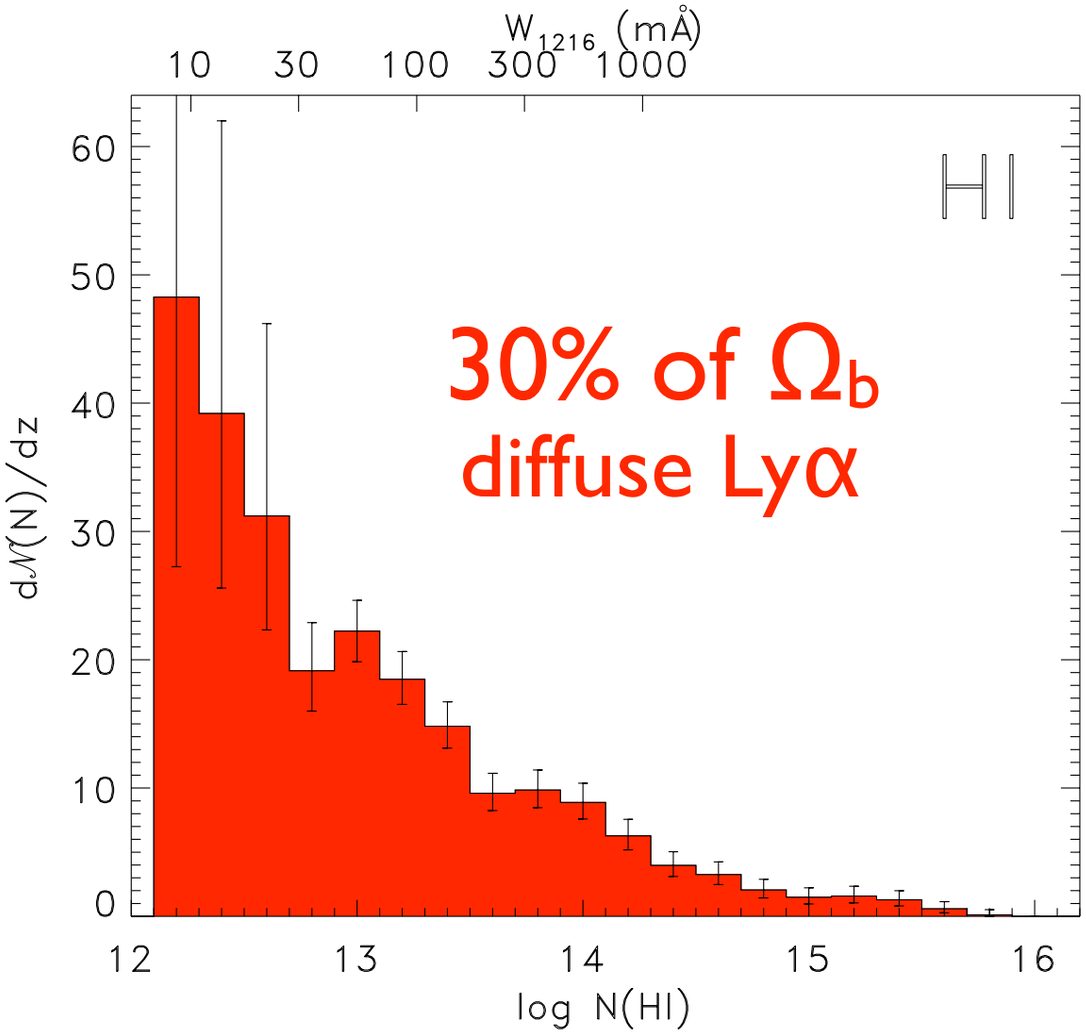
○ Probable Absorber

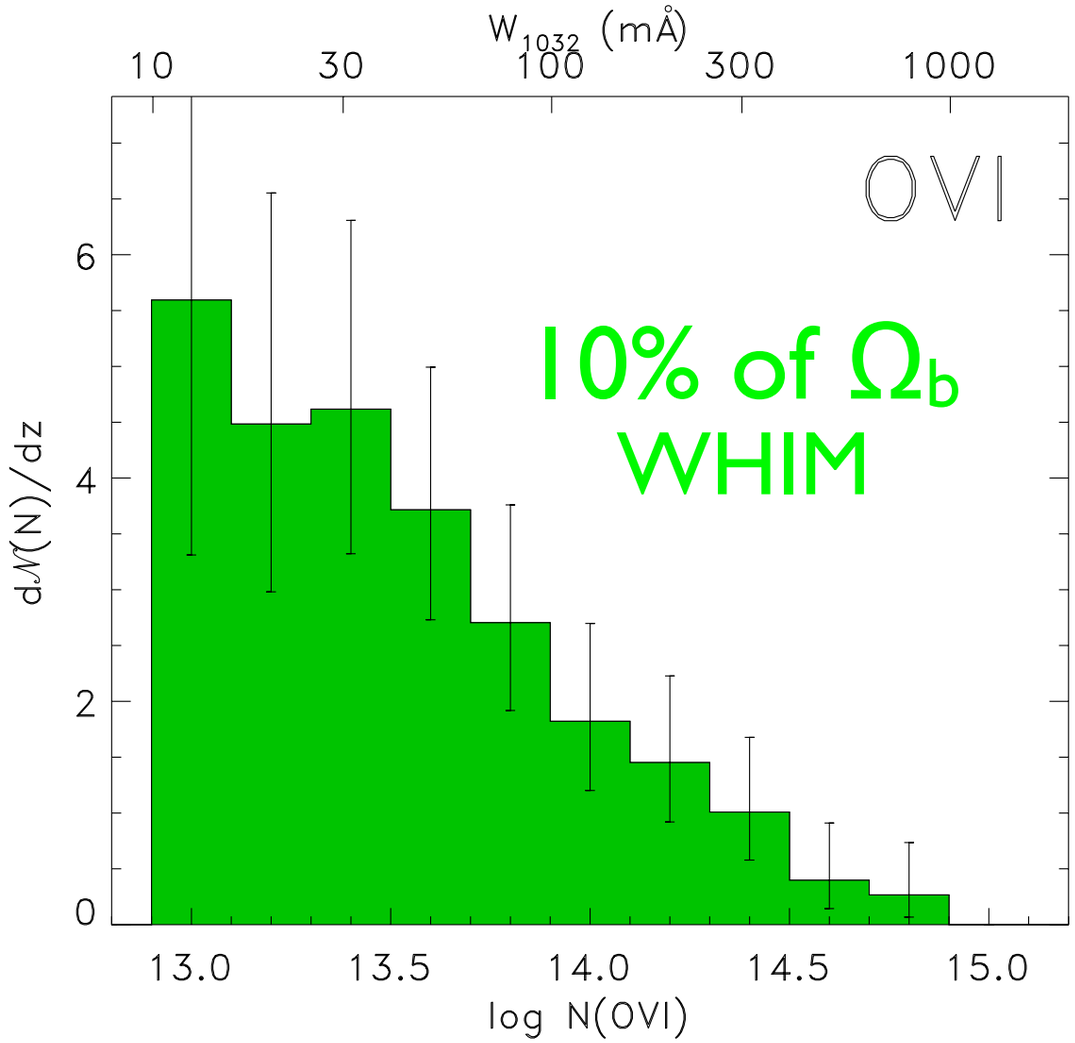
○ Definite Absorber

□ = MRK 501

○ = MRK 421

α wedge for δ = 32.50 ± 5.0°



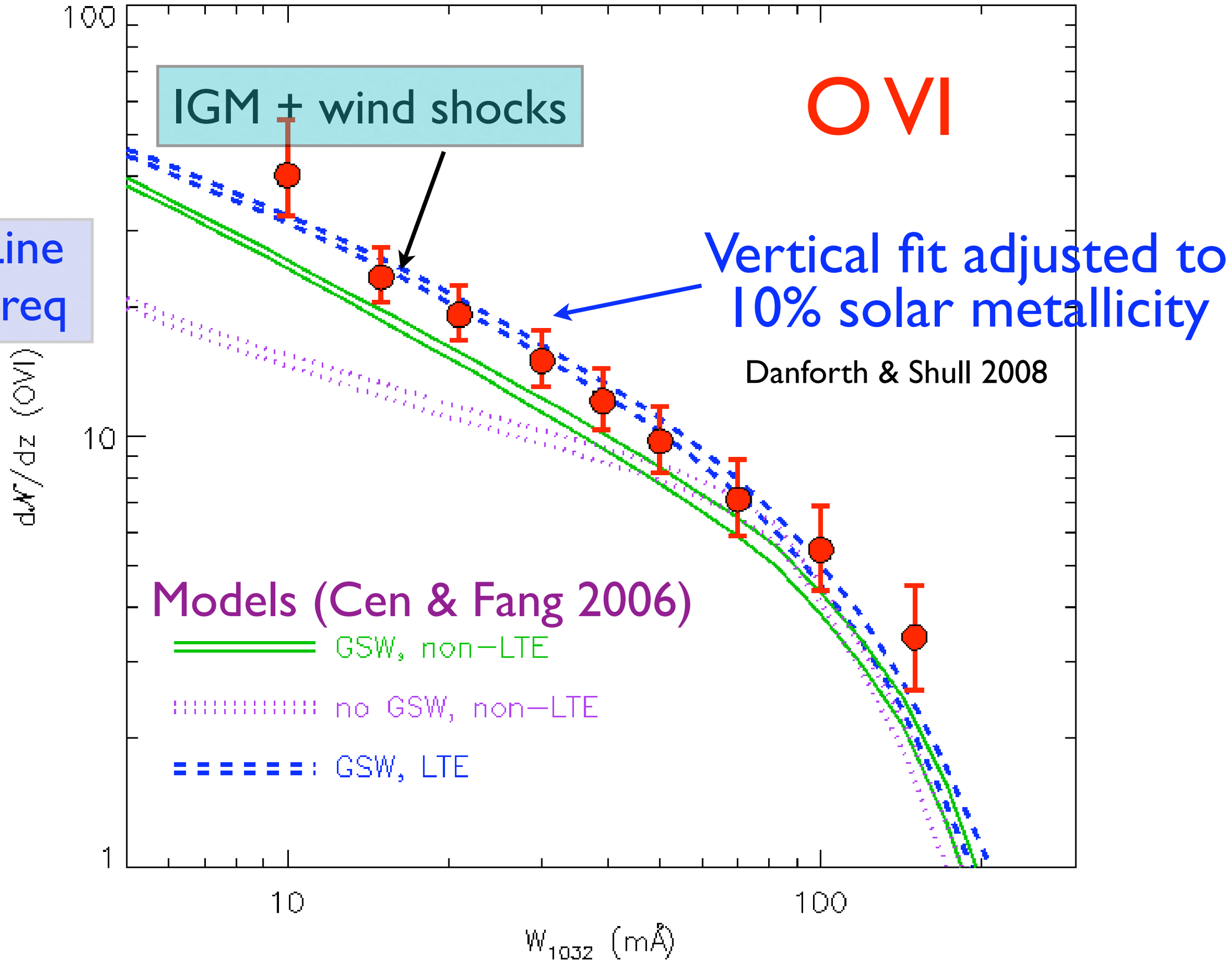


$\mathcal{N}$=650, β=1.73±0.04

$\mathcal{N}$=83, β=1.98±0.11

Danforth & Shull 2008, ApJ, 679 in press (May 20)

➥ ***arXiv:0709.4030***

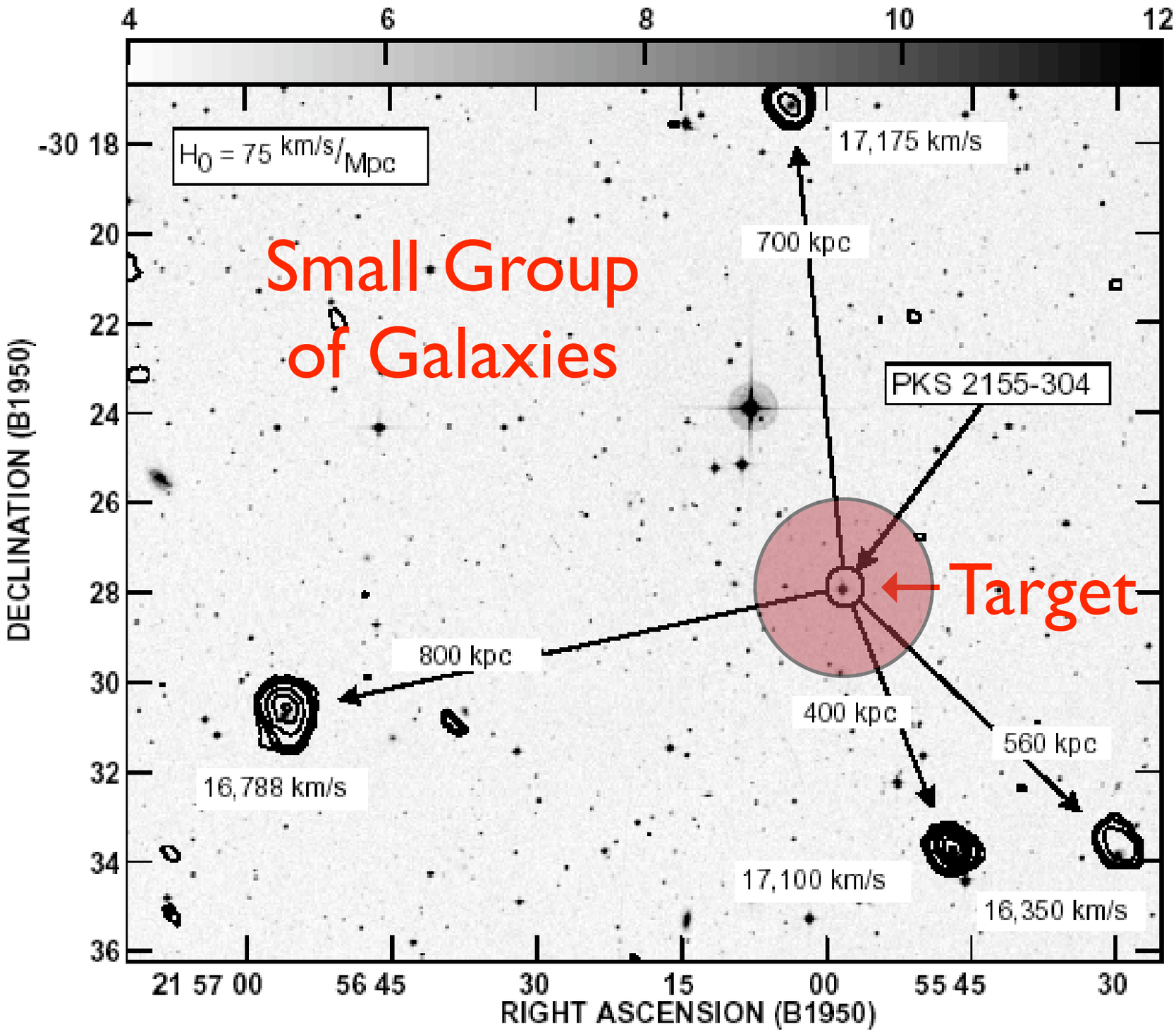


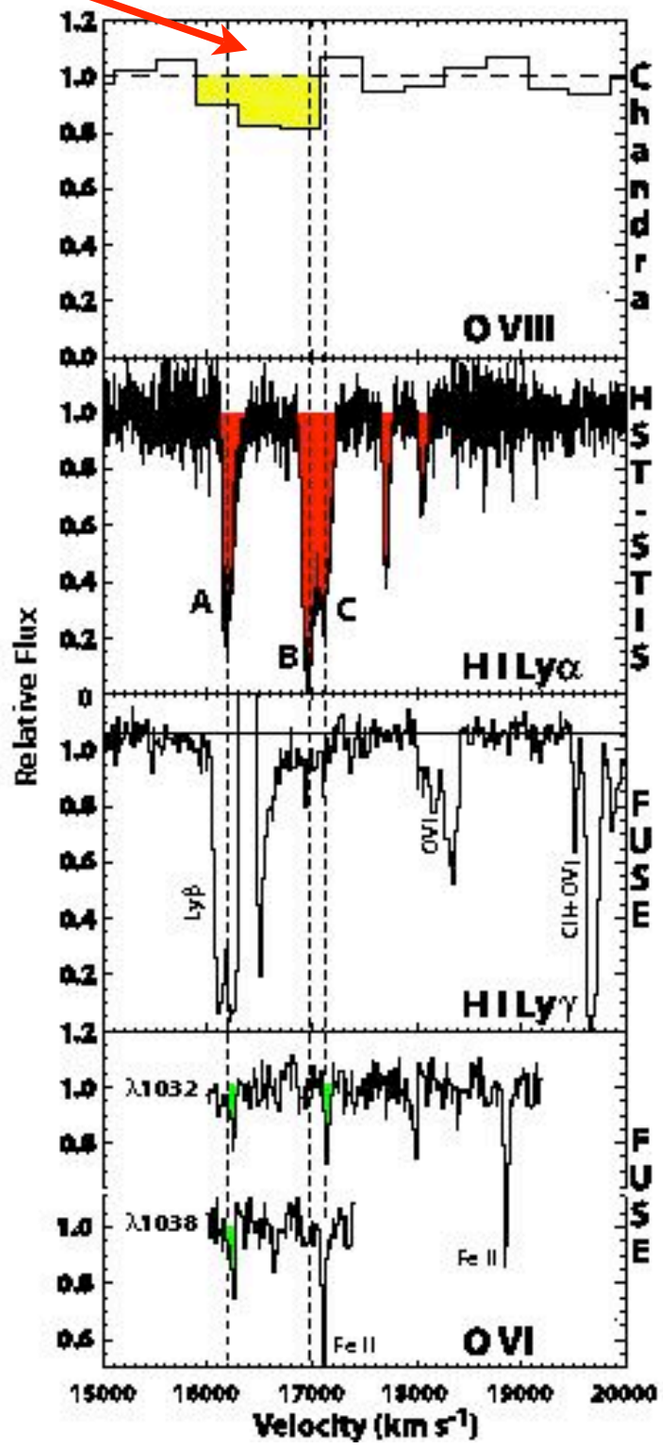
O VI Absorber Strength

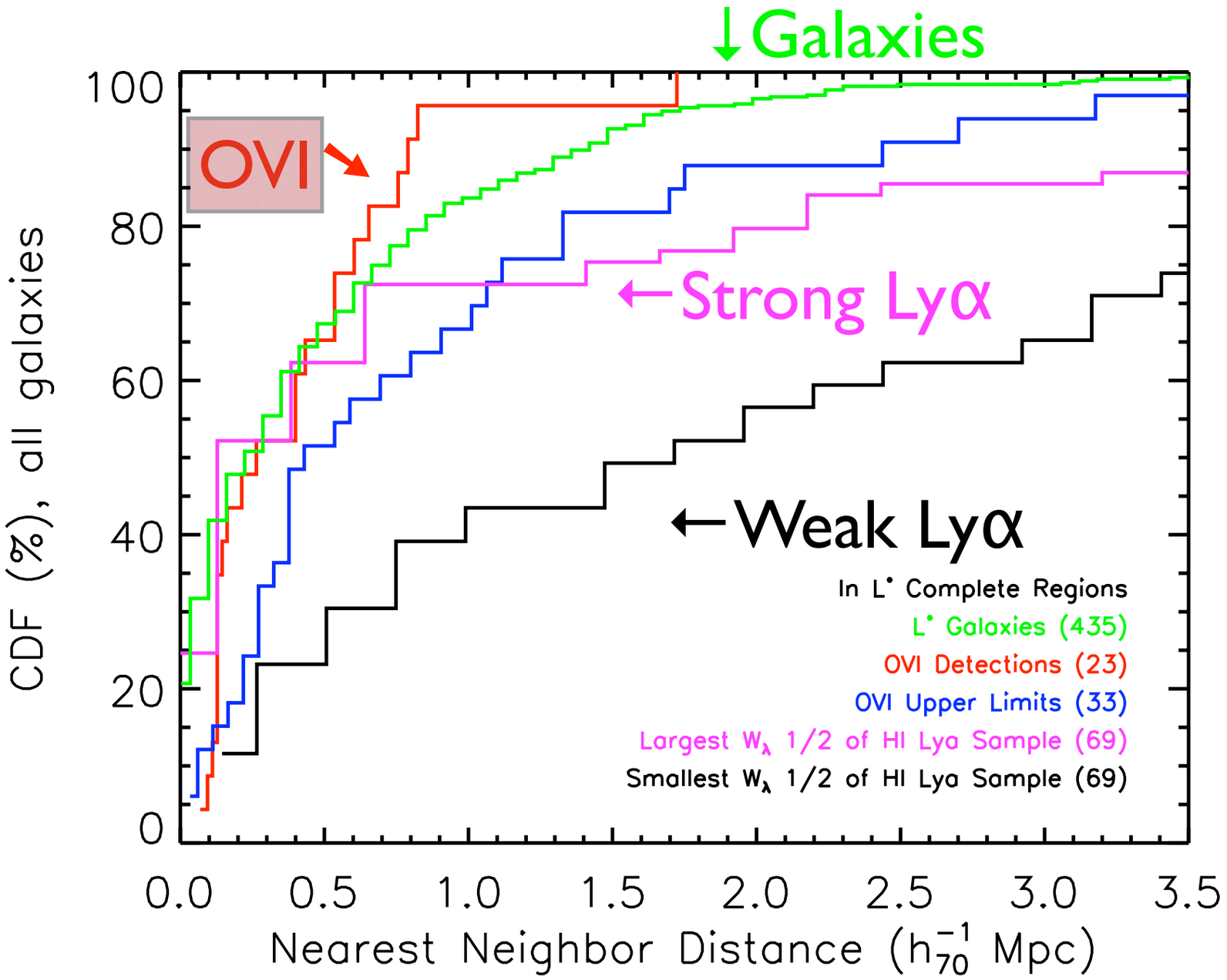
Galaxy/Lyα absorbers (PKS 2155-304)
Group at z ≈ 0.053 Shull et al. (1998, 2004)

Chandra, HST, and FUSE data

X-ray (O VIII absorber?) - Fang et al 2005, 2008







Nearest-galaxy distributions

Stocke et al. (2006)

OVI absorbers track galaxies:

OVI absorbers lie within 800 kpc of L* galaxies

& within 200 kpc of 0.1 L* galaxies

Summary of Results:

We have accounted for ~50% of the baryons

- 10% in collapsed structures (galaxies, clusters)
- 30% in warm (10^4 K) photoionized gas (Lyα)
- 10% in hot ($10^{5.5}$ K) gas (O VI ultraviolet lines)

Other 50% may be in even hotter (10^6 K) gas

Need ConX

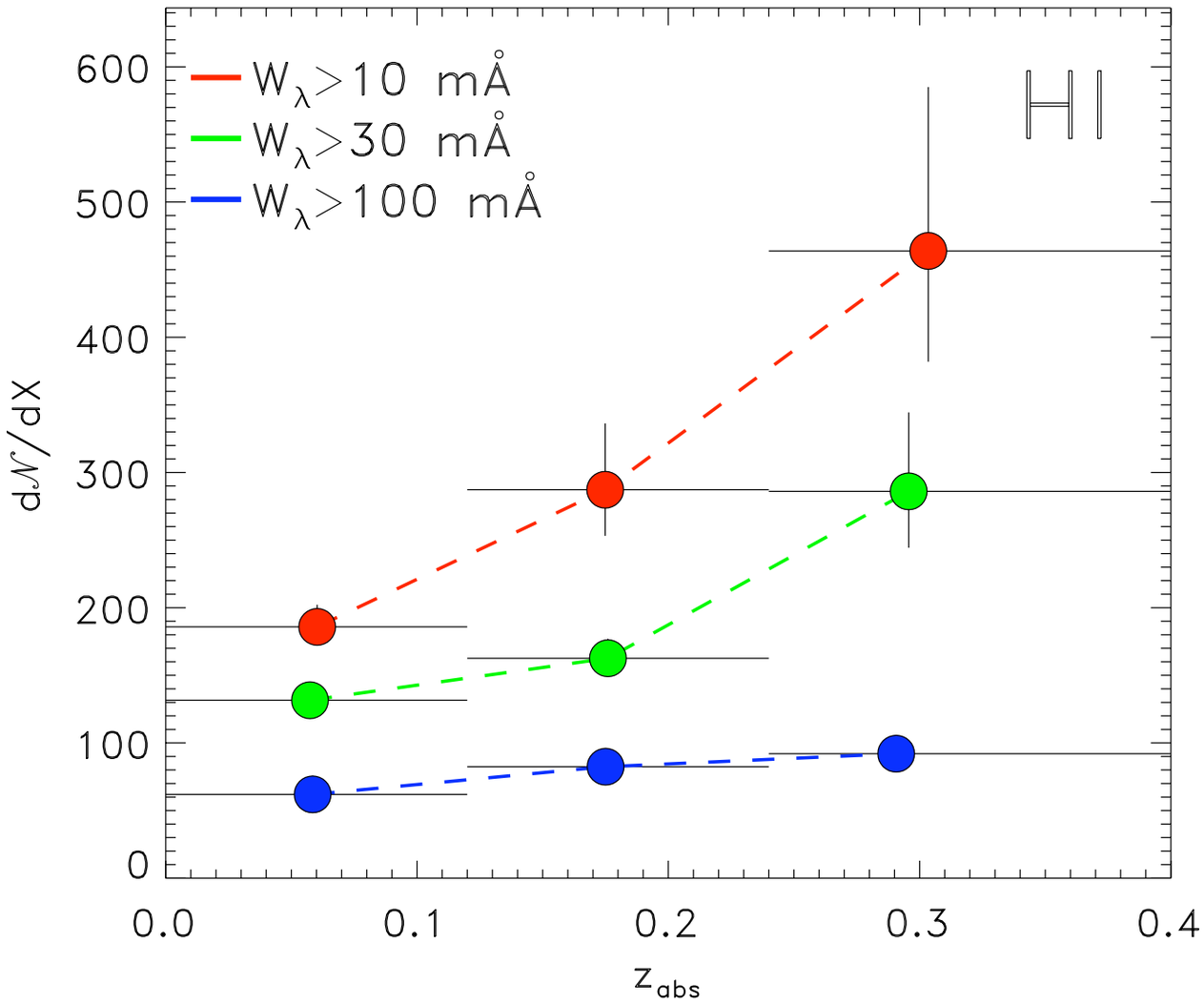
The hot (O VI) gas is close to galaxies, and thus is a reservoir for low-Z gas infall

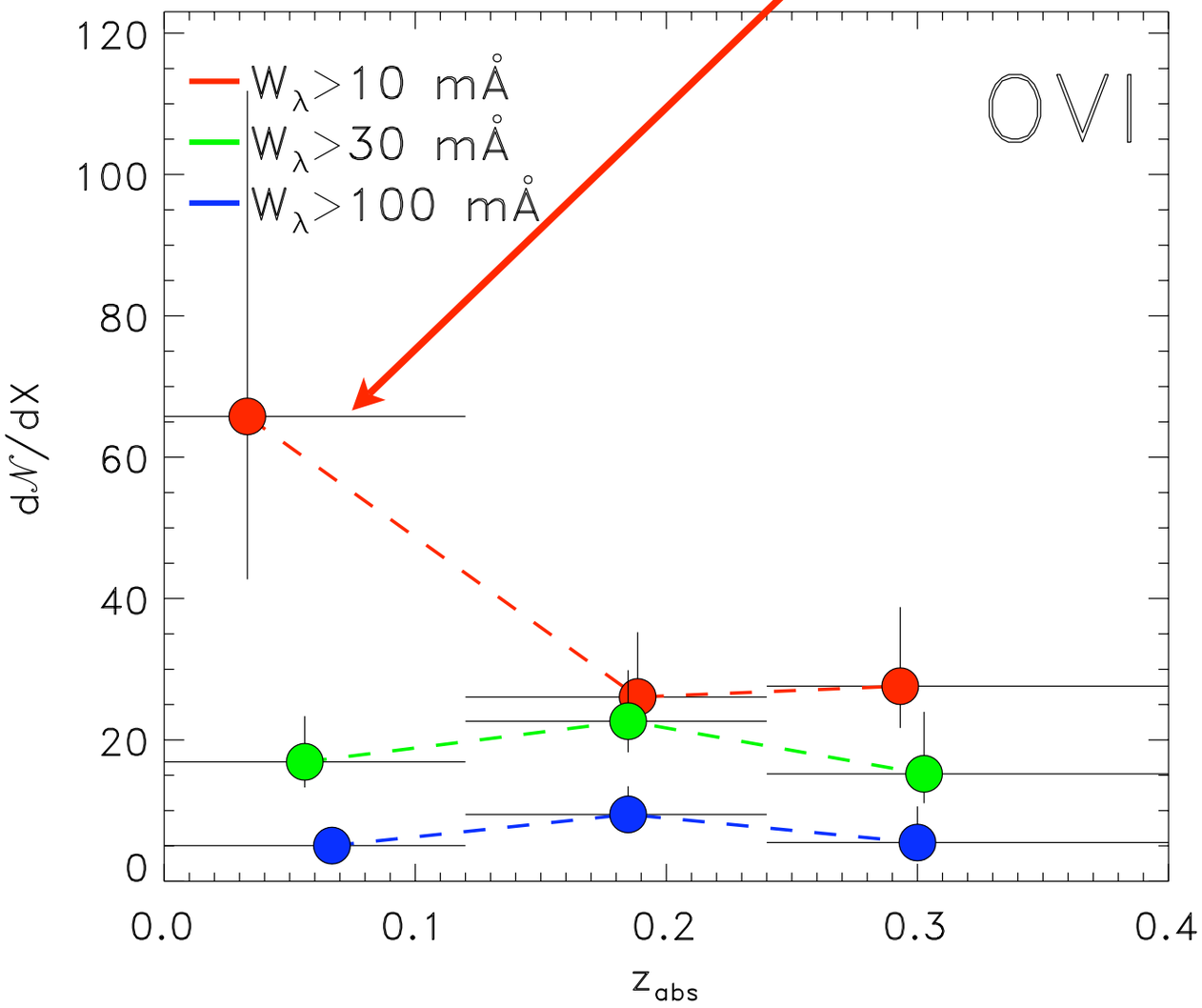
- Within 200 kpc of 0.1 L^* galaxies (outflows?)
- Cooling ⇒ 0.1 M_{sun}/yr gaseous infall to halos?

IGM Absorber Redshift Evolution

(We see a hint of this already)

Are shocked WHIM filaments stronger at low z?





Shull & Danforth 2008

IGM/Halo Hubble Key Project (sample)

500 orbits: High-S/N Survey (R = 20,000)

G130M/G160M (50 targets, 10 orbits each, S/N = 30-40)

Large redshift coverage ($\Delta z \approx 20$)

10,000 Lyα, 500 O VI absorbers, many metal lines

200 orbits: mid-UV spectral survey (z = 0 to 1.5)

Baryons & metal evolution out to z > 1

100 orbits: low-resolution survey

100 AGN targets with G140L (R = 3000)

Cosmology (power-spectra, voids, web geometry)

Survey for DLA and Lyman-limit systems

Plans for Con-X in IGM/Halo Studies

Need sensitivity and spectral resolution below 1 keV to trace key lines (O VII, O VIII, Ne, N, C ions). Background AGN with F ≈10^{-12} erg cm^{-2} s^{-1} (0.1-0.2 mCrab)

Tie X-ray absorbers to the UV lines (Lyα, O VI, N V, C III, C IV, Si III, Fe III, etc) - wavelength scale ±20 km/s?

R = 1500 (minimum) and 3000 (goal) in order to match 100 km/s thermal line widths and increase sensitivity to 10^6 K gas with $N_{OVII} \geq 10^{14}$ cm^{-2}

$$\Delta v_{FWHM} = (53.5 \text{ km/s})\, T_6^{1/2}$$

Good News: We should have ~10^4 Lyα lines and perhaps 500 O VI lines as "UV signposts"